Study Methods

We measured mercury in several sediment cores collected from the Frankfort Flats area (*Figure 1*). We also sampled mercury in pore water of the mudflats (water in the spaces between sediment grains). Samples were processed on land adjacent to the sample locations, using an airtight "glove bag" and other precautionary measures to prevent oxygen from changing the chemistry of the sample and degrading any methylmercury that might be present. In addition, we analyzed samples for hydrogen sulfide, iron, manganese, base cations, ammonium, dissolved organic carbon, alkalinity and pH. This additional chemical data helped us to interpret the processes that lead to mercury movement and transformation.

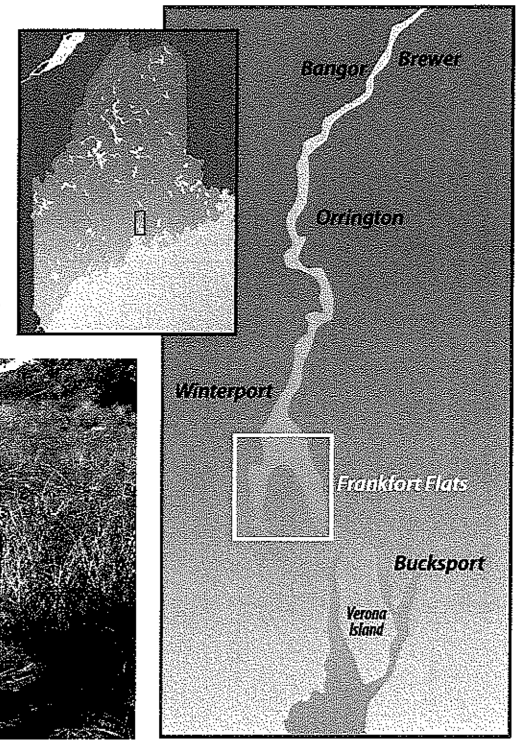


***Figure 1*: Samples were collected from Frankfort Flats**

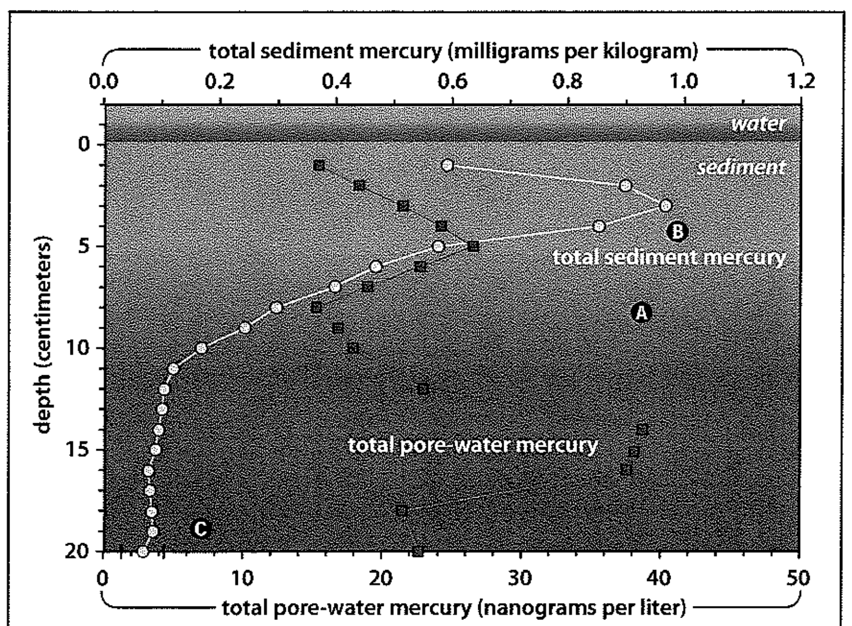
Results and Discussion

As shown in *Figure 2* Ⓐ, the concentration of total mercury (all forms of mercury, including inorganic and methylmercury) in the top five centimeters of Penobscot River estuary sediments ranges from approximately 0.4 to 1.0 milligram of mercury per kilogram of dry sediment (or parts per million, ppm). While sediment mercury concentration generally increases with organic matter content, the sharp peak in sediment mercury we observed in the top five centimeters does not correspond to a high organic matter content. It is instead due to the point source of mercury pollution (Ⓑ).

At the studied mudflat, sediment accumulates at a rate of about 1 millimeter per year. In *Figure 2*, sediment depth corresponds with sediment age (the deeper the sediment, the older it is).

At depth, sediment mercury concentration drops to the observed background New England level of approximately 0.04 ppm that represents older, pre-industrial sediment deposition. This "background" mercury enters the environment from natural processes such as weathering of rocks and volcanic eruptions Ⓒ.

***Figure 2*: Mercury distribution in the sediment and pore water.** The lines show whether mercury in sediment (orange circle symbol) and mercury in pore water (red symbol; water in the spaces between sediment grains) increases or decreases with sediment depth (vertical Y axis).



Estuaries act as storage sites for mercury.

Mercury released into the river tends to stick to particles in the water, especially particles that are mostly organic matter. In the tidal mixing of the estuary, particles tend to settle out of the water, forming extensive mudflats and marshes, as in Frankfort Flats and the Mendall Marsh Wildlife Management areas near the confluence of the Marsh and Penobscot rivers. Sediments in these areas store particulate (solid) mercury and organic matter. The total mercury profile in *Figure 2* (○) shows that the Penobscot River estuary sediments indeed act as a long-term storage for particulate mercury.

Estuaries can be sources of mercury.

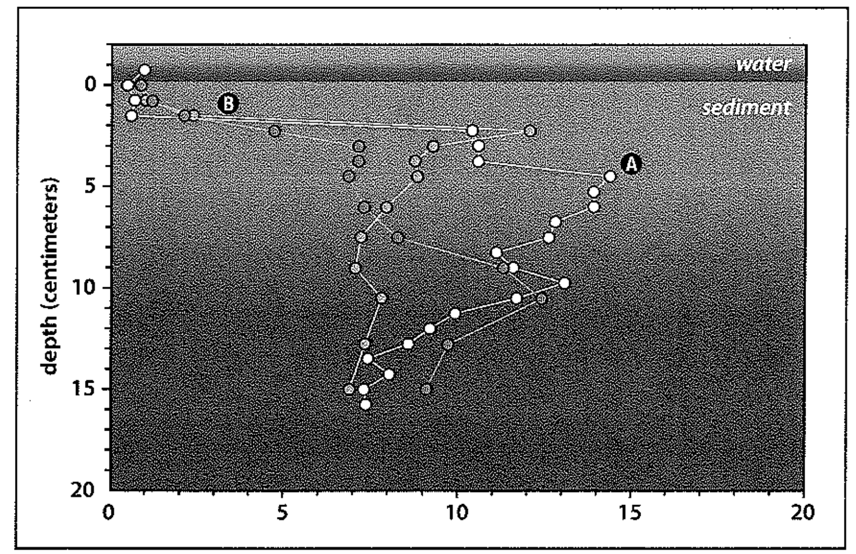
The pore-water total mercury profile in *Figure 2* (■) shows that the Penobscot River estuary sediments act as a source of dissolved mercury to the overlying water. Pore-water mercury is mobilized in the presence of hydrogen sulfide, which exists in estuarine sediments at high concentrations. Mercury is released at depths where the density of iron and sulfur bacteria is the highest.

Estuarine sediments produce toxic methylmercury

Sediments can be a source of dissolved mercury and organic matter because of the activity of microorganisms. As the deposited mercury is buried beneath new layers of sediment, organic matter in the sediment is consumed by certain types of bacteria living a few millimeters below the sediment-water interface, beyond the reach of oxygen. These bacteria get their energy through chemical reactions that involve sulfur and iron, and produce toxic methylmercury as a byproduct.

Figure 3 Ⓐ shows a significant production of pore-water methylmercury at a depth of approximately five centimeters, where a concentration as high as 15 ppt is observed. Methylmercury can travel up or down through the sediment. *Figure 3* Ⓑ also shows that pore-water methylmercury rapidly disappears between a depth of one and two centimeters, inhibiting the release of this toxic chemical into the water. The exact reason for this is not known. Some bacteria can actually convert methylmercury back into the less toxic form of inorganic mercury. Or, the methylmercury that is diffusing up may get adsorbed by a relatively high concentration of iron hydroxide close to the sediment-water interface.

***Figure 3*: Pore-water methylmercury concentrations (nanograms per liter) in three cores.** The lines show concentrations of biologically-active, toxic methylmercury in three core samples of sediment pore-water.



The lack of methylmercury release into the overlying water from the studied sediments does not mean that the animals in the mud and water are not exposed to this toxic chemical. Methylmercury may be directly taken up by deposit-feeding and burrowing organisms, such as worms and clams, and move up the food chain.

In other experiments, we have found that semi-permanent flooding or ponding, as would happen in a salt marsh panne, can create conditions where methylmercury released to the overlying water is greatly enhanced. With sea level rise, many coastal freshwater wetlands will be flooded with seawater, and may act as "hoptspots" for methylmercury release.

In mudflats, regular flooding and exposure with changing tides can create conditions that lead to rapid mercury methylation and release into the overlying water. Future research will look at mercury concentrations in marsh plants, sediments, and animals living in the mudflats.

Do mercury levels in the Penobscot River estuary threaten the health of fish, wildlife, or humans?

Mercury in the Penobscot River is currently under a U.S. District Court-ordered investigation by an international team of expert scientists. Phase I of the study was completed and approved by the court in March 2008.

The study team sampled water, sediments, wetlands, benthic invertebrates, fish, shellfish, birds and mammals in the Penobscot River and estuary in 2006 and 2007. The researchers found that mercury concentrations decreased with increasing distance from the HoltraChem site. The most severe contamination of the Penobscot system is between Brewer on the lower river and about Fort Point or Sears Island in the upper estuary. They also found that:

- Mercury in the sediments was 20 times more concentrated in the lower river and estuary compared to a reference area in the East Branch Penobscot River.
- Mercury attached to particles suspended in the water was two times higher downstream of the Holtrachem site.
- In some individual lobsters, levels of methylmercury in claw and tail muscle exceeded the Maine DEP and U.S. EPA criteria for protection of human health.
- Mercury in mussels was high compared to other sites in Maine and the U.S.
- Mercury levels in songbirds inhabiting wetlands adjacent to the lower Penobscot River in the Frankfort Flats area were very high compared to levels in songbirds in other parts of Maine, and high enough for possible toxic effects on the birds themselves.

- Mercury in cormorant eggs in the upper estuary approached or exceeded levels thought to impair reproduction.

The study's authors concluded, "The Penobscot River and estuary are contaminated with mercury to an extent that poses endangerment to some wildlife species and possibly some limited risk for human consumers of fish and shellfish."

Phase II of the study will concentrate on understanding where and when mercury is produced in the system, and how it is transported and bioaccumulated in the lower river and upper estuary. Data from the study will be used to evaluate the practicality of possible mitigation measures.

All of Maine's lakes and rivers are posted with a fish consumption advisory due to mercury contamination. Most of this mercury enters surface waters when rain, snow, and dust fall from the atmosphere. Mercury gets into the air primarily from coal-fired power plants upwind of Maine.

State of Maine Fish Consumption Advisory

Maine Center for Disease Control & Prevention, Department of Health and Human Services

For pregnant and nursing women, women who may get pregnant, and children under age 8:

Do NOT eat swordfish, shark, king mackerel, tilefish, pike, pickerel, largemouth bass, smallmouth bass, white perch, lake trout, or brown trout. These fish are high in mercury because they eat other fish or live a long time.

Limit tuna and halibut to one meal per week.

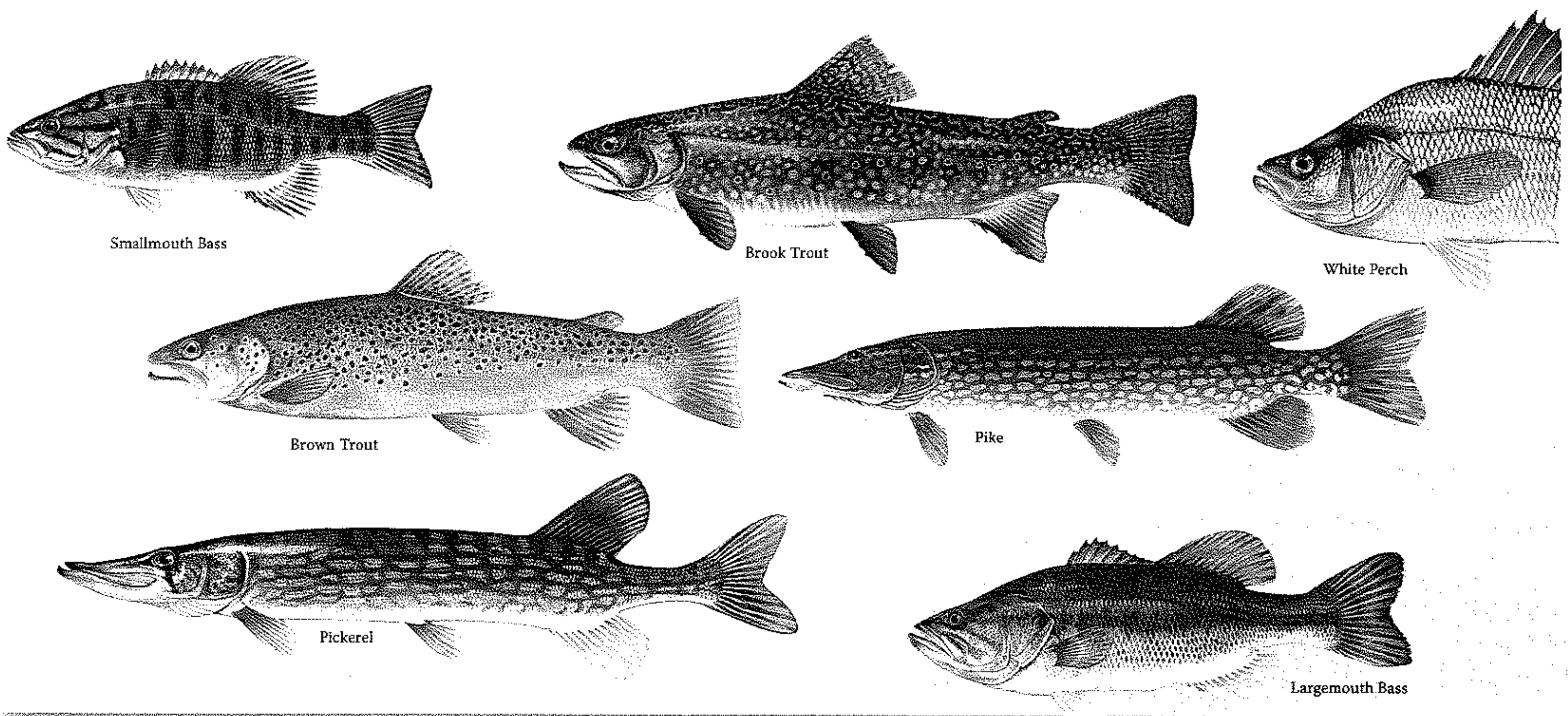
Limit lake smelt, landlocked salmon, and brook trout to one meal per month.

For other adults and children over age 8:

Up to 2 meals per month of swordfish, shark, king mackerel, tilefish, pike, pickerel, largemouth bass, smallmouth bass, white perch, lake trout, or brown trout.

1 meal per week of lake smelt, landlocked salmon, and brook trout.

Saltwater sport fish such as Atlantic mackerel and sea-run smelts are safe and healthy for everyone.



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Marine RESEARCH *in focus*

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Mercury in the Penobscot River Estuary: The Sediment-Water Interface

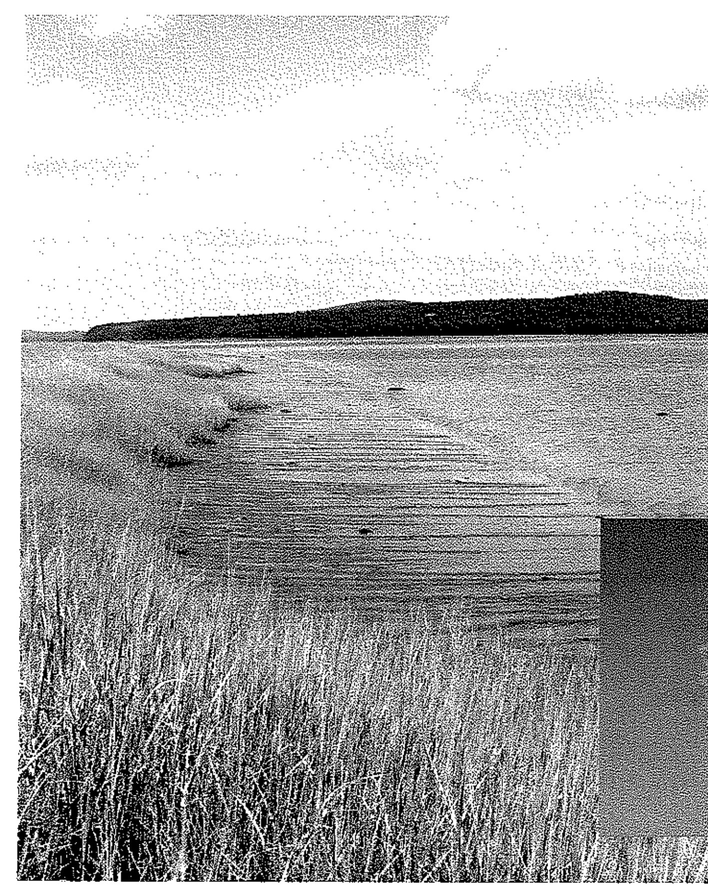
by Aria Amirbahman and Karen A. Merritt

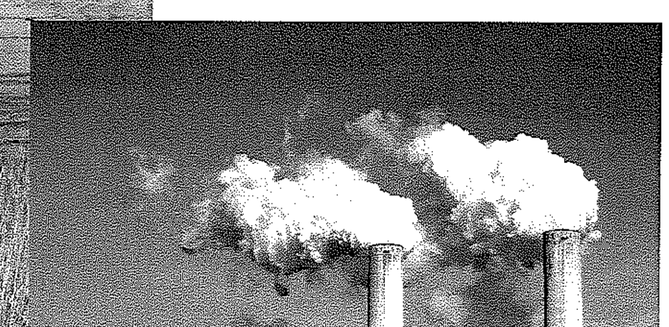
Background

Mercury is released into the air by natural events, such as volcanic eruptions, and human activities, including fossil fuel combustion, waste burning, and industrial processes. Mercury is deposited to surface waters from the atmosphere via dust, rain, and snow. Paper mills along the Penobscot River historically may have used mercury-containing chemicals. As well as upriver paper mill activity, several point sources of mercury pollution exist within the estuary, including a waste incinerator and a recently-closed chlor-alkali production facility (HoltraChem) that used mercury to make chlorine and other chemicals.

In the environment, mercury is converted to methylmercury, the form that is readily taken up by living things. Methylmercury concentrations magnify with each step in the food web: from bacteria to insects to songbirds, from algae to zooplankton to tiny fish to bigger fish. Humans are exposed to mercury primarily by eating contaminated seafood. Estuarine and coastal sediments are ideal sites for the production of toxic methylmercury. In fact, the methylmercury produced in coastal zones may account for the bulk of mercury contamination in ocean fish.

In this fact sheet we present the results of ongoing studies to understand the patterns and effects of mercury in the Penobscot River estuary.





Mercury is a highly toxic element that can impair brain development in children, and affect cognition, hearing, vision, and muscle coordination in adults. Mercury can be toxic to wildlife.

Sea Grant Maine

Marine Research in focus provides updates on marine research for coastal communities. This fact sheet was produced by Maine Sea Grant with programing support provided by University of Maine Cooperative Extension.

The University of Maine Cooperative Extension